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CLIMATOLOGY AND VEGETATION IN COLORADO

W. W. Robbins

(WITH SEVEN FIGURES)

To the student of botany, it matters not in what part of the United States he lives or in what branch of botanical work he is engaged, the state of Colorado is an interesting and attractive area. The general inland location of the state, great differences of altitude, of latitude, and of topography, are factors which bring about varied climatic conditions, resulting in corresponding vegetative differences. It is the purpose of this paper to give a general view of the climatological conditions of Colorado in their relation to vegetation. The necessity of pointing out in ecological and phytogeographical studies the relation between the climatology of an area, extended or restricted in its range, and the vegetative covering, is being increasingly recognized. The climatologist and the field botanist must join hands. Not only is the botanist coming to realize his dependence upon a thorough knowledge of climatology as a basis for his phytogeographical studies, but in a like manner is the climatologist coming to see that the distribution of the indigenous vegetation will aid him. This fact has been recognized by the Maryland Weather Service, which has undertaken a botanical survey of that state as a part of its climatic studies.

Physiography and climatology

PHYSIOGRAPHY

TOPOGRAPHY.—The general topographic features of the state are given in *fig. 1*. The eastern half of the state is plains. This region is limited on the west by the foothills, which extend from the northern to the southern borders of the state, following closely the 6000-foot contour line. The foothills rise one over the other, extending westward to the main range. The continental divide passes irregularly in a north and south direction through the state. It is therefore a barrier to the east and west distribution of plants. In the mountainous region there are four large parks or high valleys: North, Middle, South, and San Luis parks. They are broad, level expanses of country having an elevation of 6000–10,000 feet and inclosed by high mountains; hence they are very dry and the vegetation is more xerophytic than that growing at the same altitudes in uninclosed areas. There are parts of western Colorado, however, where xerophytic conditions exist at high altitudes, the dryness in this case being due to the unequal seasonal distribution of precipitation. Western Colorado is for the most part high; high, flat tablelands and mesas, dissected by narrow steep canyons, are characteristic. Many of the minor mountain ranges have an east and west trend.

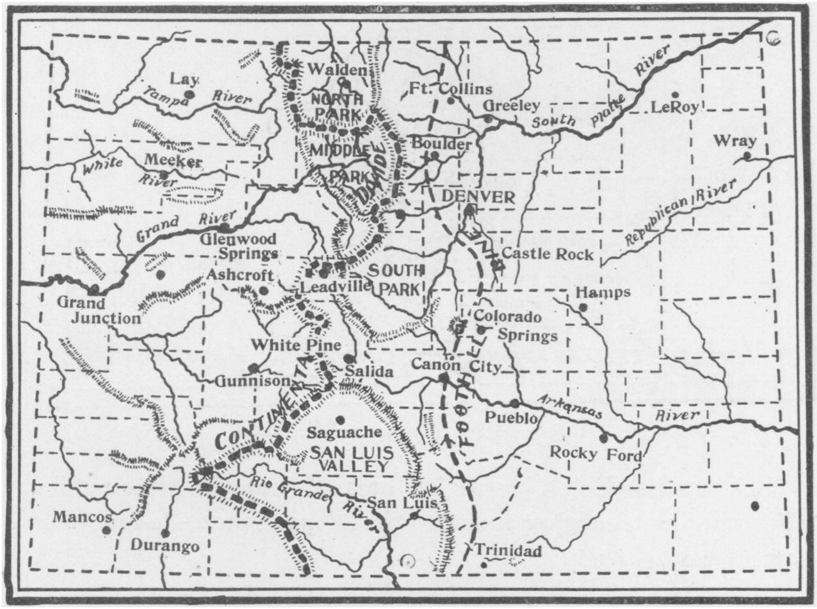

FIG. 1.—General topographic features of the state; east of the foothill line lie the great plains.

An important topographic feature of the eastern part of the state is the Arkansas-Platte Divide, extending plainward from the foothills in the middle of the state. Foothill forms of vegetation have an eastward extension on this divide. It also marks the northern and southern limit of some species, such as the pinyon pine (*Pinus edulis* Engelm.), the chandelier cactus (*Opuntia arborescens* Engelm.), and *Populus Wislizenii* (S. Wats.) Sarg., which do not occur north of the divide. The same is true to a less extent of the scrub oak; on the eastern slope this plant is not abundant north of the Arkansas-Platte Divide.

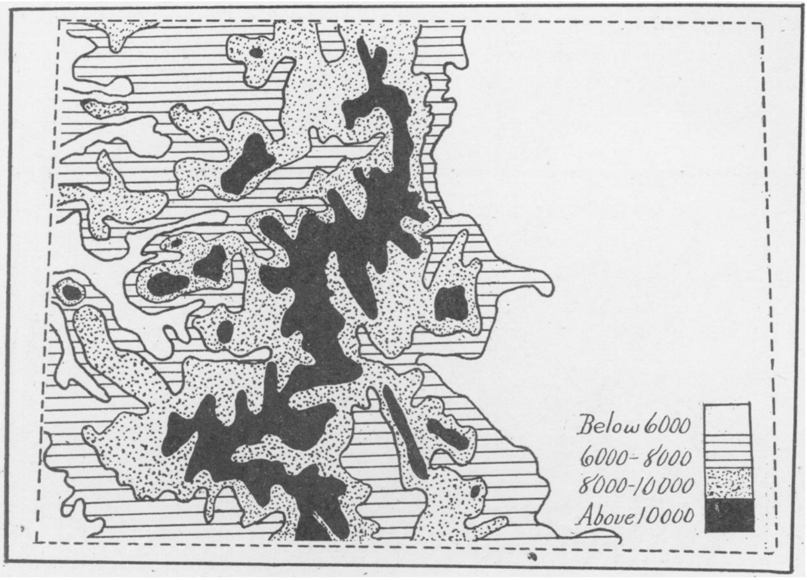

FIG. 2.—Mass elevations of Colorado.

ELEVATION.—Colorado has an area of 103,480 square miles.[1] The following table gives the mass elevations of the state in area and percentages.

TABLE I

MASS ELEVATIONS

Elevation	Area in sq. miles	Percentage of total area
6000 feet and below	45,000	43
6000–8000 feet..............	22,000	20
8000–10,000 feet	24,000	23
10,000 feet and above........	12,500	14

From the above table and the accompanying map showing mass elevations (*fig. 2*), it is seen that a great proportion of the state is highly mountainous. The lowest point in the state has an elevation of 3386 feet; there are a number of peaks over 14,000 feet high; thus there is an altitudinal range considerably over 11,500 feet.

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[1] GANNETT, HENRY, Report U. S. Geol. and Geog. Survey of the Territories (Hayden Survey) 313. 1876.

DRAINAGE SYSTEMS.—The general north and south direction of the mountains of Colorado determines the general east and west direction of the streams. In the mountainous country small streams are very abundant, and they usually have their head in a wet mountain meadow which is fed by water from melting snow. The prevalent east and west direction of the streams is a condition affecting the migration of riparian species. Generally speaking, the streamside flora and vegetation at any point is more like that east and west than that north and south.

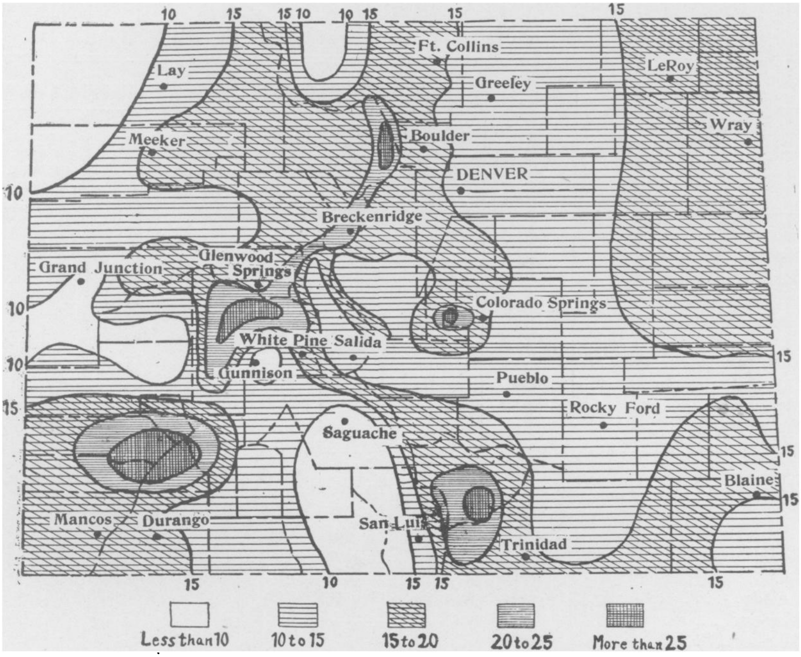

FIG. 3.—Mean annual precipitation: the area along the eastern border of the state having 15–20 inches annually is called the "rainbelt"; dry farming is more successful here than in the belt on the west of it.

PRECIPITATION

GENERAL ACCOUNT.—The precipitation amounts of Colorado are shown in *fig. 3*. In making a rainfall map it is found difficult to depend upon rain gauge records alone, because of the variety of conditions at intermediate points which are brought about by topographical conditions. Hence in preparing this map, as well as the ones of temperature, the influence of the larger topographic features and of altitude have been taken into consideration. Fortunately, however, the meteorological stations in Colorado are numerous enough and so happily distributed, that one is able to rely upon them as being fairly representative.

TABLE II

SEASONAL DISTRIBUTION OF PRECIPITATION EAST AND WEST OF DIVIDE

STATION	ALT. (FEET)	EAST OF CONTINENTAL DIVIDE			WEST OF CONTINENTAL DIVIDE		
		Mean for growing season	Mean for year	Perc'tage during growing season	Mean for growing season	Mean for year	Perc'tage during growing season
Ashcroft	9483	. . . . .	. . . . .	. .	10.67	19.38	55
Blaine	3935	12.36	16.08	77			
Boulder	5347	12.83	18.46	69			
Breckenridge	9536	. . . . .	. . . . .	. .	11.99	26.76	72
Castle Rock	6220	12.73	17.65	72			
Cheyenne	6088	9.40	12.20	77			
Collbran	6000	. . . . .	. . . . .	. .	7.33	14.59	50
Colorado Springs	6098	13.00	14.41	90			
Denver	5272	10.03	14.02	72			
Durango	6534	. . . . .	. . . . .	. .	8.25	16.62	50
Ft. Collins	4985	11.06	14.91	73			
Grand Junction	4608	. . . . .	. . . . .	. .	4.27	8.50	50
Hamps	5400	11.82	14.56	81			
Holly	3386	12.71	15.32	71			
Idaho Springs	7543	10.65	15.44	68			
Lake Moraine	10625	18.44	25.59	72			
Lay	6162	. . . . .	. . . . .	. .	6.37	12.72	50
LeRoy	4380	12.22	16.05	76			
Mancos	6960	. . . . .	. . . . .	. .	9.29	17.29	53
Meeker	6182	. . . . .	. . . . .	. .	8.42	15.91	53
Pike's Peak	14108	19.07	28.65	66			
Pueblo	4734	9.17	12.11	75			
Saguache	7745	5.45	7.21	75			
Salida	7035	7.62	11.47	67			
Wray	3512	14.57	18.11	80			
Mean average		11.84	15.90	74	8.57	16.45	52

The eastern part of the state has more rain (15–20 inches) than a strip closer to the mountains (10–15 inches). On the eastern slope of the mountains, localities between 6000 and 10,000 feet altitude have an annual precipitation of 15–20 inches; many localities have greater amounts. The higher mountainous parts receive over 20 inches annually. North, Middle, and San Luis parks are very dry, the annual precipitation being less than 10 inches; South Park is drier than localities at the same altitude on the eastern slope. On the western slope there is a gradual decrease westward in the annual rainfall, which becomes on the western border less than 10 inches.

SEASONAL DISTRIBUTION.—The precipitation of Colorado shows great variability, not only in amount but also in seasonal distribution.

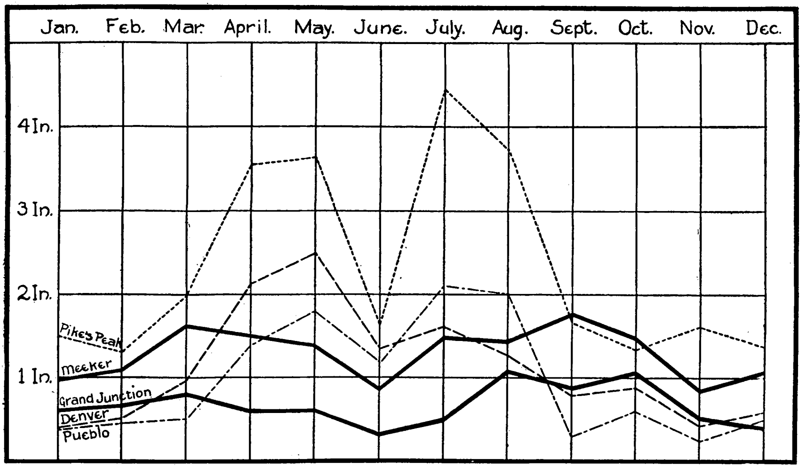

FIG. 4.—Mean annual precipitation curves: Meeker (6182 feet) and Grand Junction (4594 feet) are west of the continental divide; Pike's Peak (14,108 feet), Denver (5275 feet), and Pueblo (4672 feet) are east of the continental divide; the curves for Meeker and Grand Junction in heavy lines are very regular, showing an equal distribution of precipitation throughout the year; on the other hand, the curves for Denver, Pike's Peak, and Pueblo show for those stations a very unequal seasonal distribution; the season of maximum rainfall for each station will be noted.

From table II and *fig. 4*, it is seen that at stations east of the continental divide the greater part (average 74 per cent.) of the precipitation occurs during the growing season, when vegetation needs it, and this usually in the months of April, May, and June. On the other hand, west of the continental divide only about one-half (average 52 per cent.) occurs during the growing season, the most rainy months being July, August, and September. For this reason, so far as plant life is concerned, localities on the western slope are drier than localities at the same altitudes on the eastern slope. The precipitation of Colorado comes in showers rather than in prolonged rainy spells.

There is considerable variability as to the wettest part of the growing season. In the region north of the Arkansas-Platte Divide, the rainy months are April and May, with the exception of localities over the extreme eastern part of the state, where the maximum rainfall occurs in June. Consequently, the vernal vegetation of this region is more luxuriant than one would judge from the annual precipitation; the rest of the season is dry and is marked by the blooming of xerophytic species, mainly composites. The Arkansas-Platte Divide and the entire Arkansas Valley receive their maximum rainfall during the summer, July showing the greatest monthly amount. In the mountains July and August are the wettest months. Over the western slope the spring is wetter than the other seasons, but July or August generally shows the greatest monthly precipitation.

On account of the seasonal distribution of precipitation east of the continental divide there is very little snow. Furthermore, on account of the dry soil and air the snow soon disappears after falling. This is especially true of the plains, and as a result the vegetation does not have during the winter the protection which snow offers. The absence of snow on the plains, with the consequent low soil-moisture content, the great diurnal and annual ranges of temperature, together with the presence of a low relative humidity and dry winds, bring about conditions which account for the absence of trees.

As a result of the shortness of the rainy season, at most localities on the plains and lower foothills there is an acceleration in the growth of vegetation. Seasonal rains are usually followed by drought periods, and mesophytic plants must hasten to complete their development; hence the vegetative appearance changes rapidly.

Very wet and very dry years, or a consecutive series of these, are not uncommon in Colorado. The mean difference between the wettest and driest years is somewhat greater for localities east of the continental divide than for localities west. Plants living in a place where there are occasional very dry and very wet years must be those that have adapted themselves more or less successfully, not only to the normal precipitation, but to the variability of the same.

INCREASE OF PRECIPITATION WITH INCREASE OF ALTITUDE.[2]—It may be stated as a general rule that rainfall increases in amount and frequency with an increase in altitude. There are numerous exceptions which are due to topography. It has been pointed out by HANN (*l. c.* 305) that high mountains possess a zone of maximum precipitation above which there is a decrease. So far as the records for high altitudes in Colorado go, they indicate no such maximum zone, there being an increase to the summits.

It is well known that the increase in the amount and frequency of the precipitation in passing from lower to higher altitudes has its influence upon the vegetation. This influence finds its best expression in the arborescent vegetation. The forests on the lower slopes of the mountains are chiefly xerophytic, while those of the higher altitudes are predominantly mesophytic.

Table III gives an idea of the rate of increase of precipitation with an increase of altitude as it occurs in Colorado. Hence it indicates as well the frequency of vegetational changes, which are due in the main to precipitation amounts.

TABLE III

RATE OF INCREASE OF PRECIPITATION WITH INCREASE OF ALTITUDE

Station	Altitude (feet)	Precipitation (inches)	Number of feet increase in altitude giving increase of one inch of precipitation
Colorado Springs	6046	14.41	377
Lake Moraine	10246	25.59	1272
Pike's Peak	14108	28.65	
Denver	5272	14.02	1599
Idaho Springs	7543	15.44	
Gunnison*	7670	9.19	269
White Pine*	9500	16.00	
Glenwood Springs*	5823	13.20	592
Ashcroft*	9483	19.38	

* West of continental divide.

From the above table it will be seen that the rate of increase of precipitation is less at higher altitudes than at lower; also that on the western slope the rate of increase is more rapid than on the eastern slope.

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[2] HANN, Handbook of climatology, p. 301.

TEMPERATURE

GENERAL ACCOUNT.—*Fig. 5* shows the mean annual temperatures of Colorado. The general north-south direction of the isotherms readily shows the influence of the mountains. The eastern portion of the state and a small area along the Grand River in the western part have a mean annual temperature above 50° F.[3] The influence of the Arkansas-Platte Divide is seen in the eastward deflection of the isotherm 50. Isotherm 45 follows closely the eastern foothill line, 6000 feet altitude; it indicates the lower limit of the Rocky Mountain yellow pine (*Pinus scopulorum* [Engelm.] Lemmon). Isotherm 40 follows closely the 8000-foot contour line, and marks the lower limit of the lodgepole pine (*Pinus Murrayana* Oreg. Com.) and the usual upper limit of the Rocky Mountain yellow pine. On the western slope these isotherms run to higher altitudes. There is a decrease in the temperature with an increase in altitude, most localities

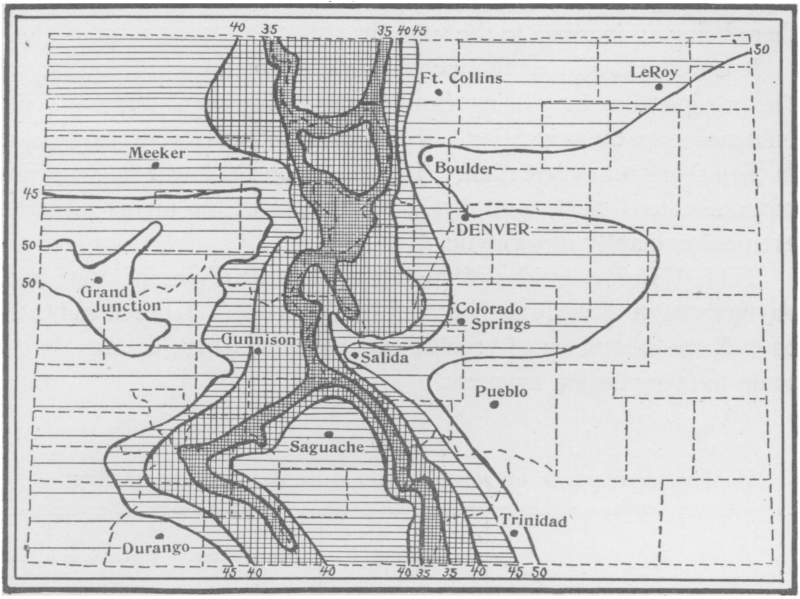

FIG. 5.—Mean annual temperatures: the general appearance of this figure is very similar to the one giving mean summer temperatures (*fig. 6*), and to the one showing mass elevations (*fig. 2*).

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[3] Throughout this paper all temperature readings are Fahrenheit.

above 10,000 feet having a mean annual temperature below 35°. Isotherm 35 follows approximately the upper limit of lodgepole pine, separating the montane from the subalpine zone. The mean autumn and spring temperatures are very nearly the same as the annual mean. As a rule, the fall mean is somewhat higher and the spring mean lower than the annual mean. *Fig. 6* gives the mean summer temperatures of Colorado. Its general appearance is similar to the mean annual temperature map. On the eastern slope isotherm 65 marks the lower limit of the foothill zone. Isotherm 60 on both slopes follows the lower limit of the montane zone and isotherm 55 the lower limit of the subalpine zone. No data are at hand to show the temperature conditions at timber line.

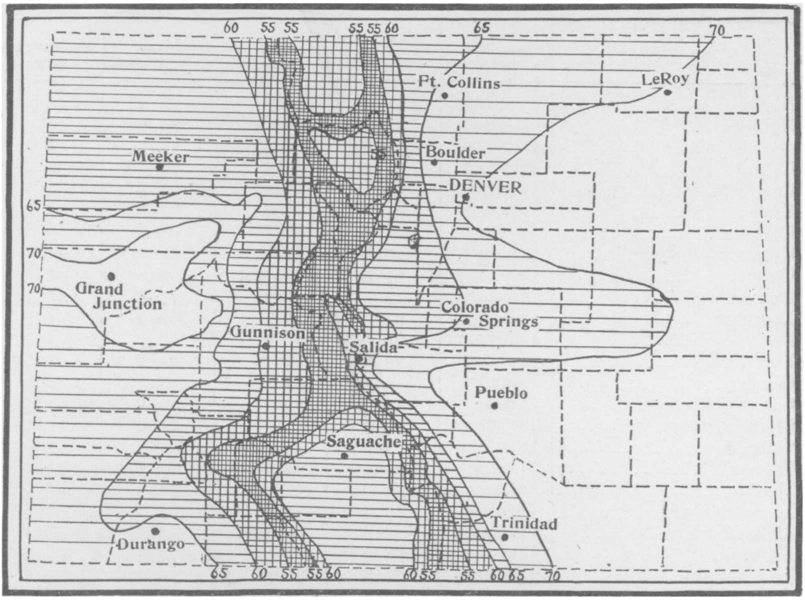

FIG. 6.—Mean summer temperatures.

RANGE OF TEMPERATURE.[4]—For the state as a whole the mean annual range (difference between the mean temperature for the warmest month and mean temperature for coldest month) is great (see table IV). In the Arkansas Valley, Platte Valley, Grand Valley,

[4] HANN, *l. c.*, p. 273.

and northwestern part of the state the mean annual range is greatest. There is a decrease in the range with an increase of altitude. The annual march of temperature for typical localities is shown in *fig. 7*. For most stations in the state January is the coldest month, July the warmest.

TABLE IV

MEAN ANNUAL RANGE OF TEMPERATURE

Locality	Coldest month	Mean temperature	Warmest month	Mean temperature	Mean annual range
Blaine	February	31.6	July	76.2	44.6
Boulder	February	30.7	August	70.7	40.0
Breckenridge	January	15.4	August	53.5	38.1
Cañon City	January	33.7	July	73.0	39.3
Castle Rock	January	26.6	July	68.3	41.7
Cheyenne	January	25.6	July	67.4	41.8
Collbran	January	22.0	July	68.8	46.8
Colorado Springs	January	27.5	July	68.0	40.5
Cope	February	27.4	August	74.9	47.5
Denver	January	29.1	July	71.8	42.7
Durango	January	24.5	July	68.7	44.2
Fort Collins	February	26.1	July	68.5	42.4
Fort Morgan	January	25.0	July	72.8	47.8
Garnett	January	14.2	July	61.1	46.9
Grand Junction	January	24.7	July	79.2	54.5
Grand Valley	January	23.9	July	72.9	49.0
Gunnison	January	7.3	July	60.9	53.6
Hamps	February	26.1	July	67.1	41.0
Hoehne	January	29.9	July	70.5	40.6
Idaho Springs	January	27.4	July	62.2	34.8
Lake Moraine	February	20.4	August	53.5	33.1
Lamar	January	31.4	July	77.5	46.1
Las Animas	January	26.4	July	76.9	50.5
Lay	January	18.1	July	67.3	49.2
LeRoy	February	25.4	August	71.5	46.1
Mancos	January	26.3	July	66.0	39.7
Meeker	January	19.6	July	65.9	46.3
Pagoda	January	19.4	July	63.9	44.5
Pueblo	January	29.1	July	74.2	45.1
Rangely	January	13.9	July	70.2	56.3
Rocky Ford	January	28.9	July	74.3	45.4
Salida	January	27.7	July	64.9	37.2
San Luis	January	19.8	July	62.8	43.0
West Cliffe	January	24.3	July	61.1	36.8
Wray	February	28.9	July	73.7	44.8

The diurnal range of temperature is great over the entire state. This is especially so on the plains, in the western part of the state, and in the parks. It is least in the higher mountain regions.

The high annual and diurnal ranges of temperature on the plains and other treeless areas of the state must receive no little consideration in explanation of the cause of the treeless condition. For example, the Rocky Mountain yellow pine will grow on the plains without irrigation if it is tided through the seedling stage. The seedling cannot tolerate great extremes of temperature.

DECREASE OF TEMPERATURE WITH INCREASE OF ALTITUDE.[5]—The rate of decrease varies with the topography, altitude, and season. It is less at high altitudes than at lower and less in winter than in summer. Table V gives the decrease in temperature for an increase in altitude for several Colorado stations.

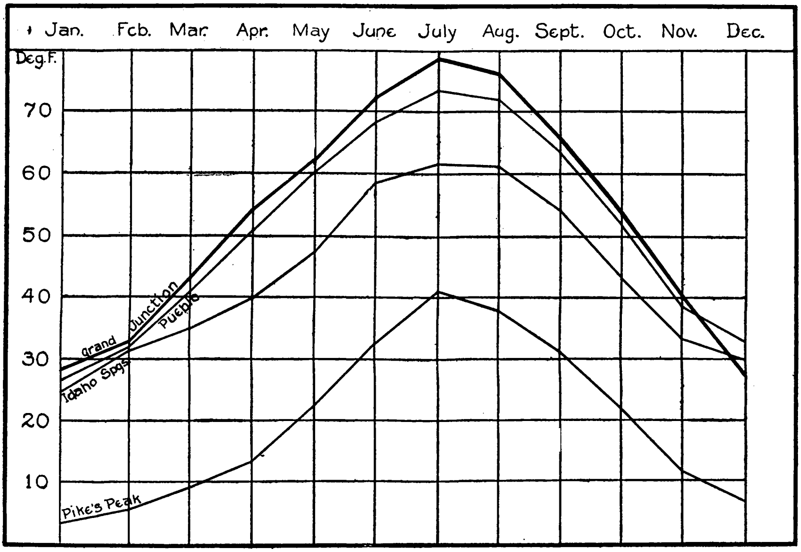

FIG. 7.—Mean annual march of temperatures: Grand Junction (4594 feet) in the western part of Colorado and Pueblo (4672 feet) on the plains have a much smaller range of temperature than do the mountain stations Idaho Springs (7453 feet) and Pike's Peak (14,108 feet).

Colorado Springs is at the base of Pike's Peak; Lake Moraine is at an elevation of 10,265 feet on its eastern slope. It will be seen from the table that the decrease of temperature between Lake Moraine and Colorado Springs is less than that between Lake Moraine and Pike's Peak. This is contrary to the general rule, and is probably due to the inversion of temperature which occurs at the base of the mountain, bringing the mean temperature of Colorado Springs lower than it would be if inversion did not take place. The data for the last three sets of localities in the table are for one season only.

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[5] HANN, *l. c.*, p. 243.

TABLE V

DECREASE IN TEMPERATURE WITH INCREASE OF ALTITUDE

Stations compared	Decrease of temperature per 1000 feet (in degrees F.)
Pike's Peak–Colorado Springs*	3.4
Pike's Peak–Lake Moraine*	4.3
Lake Moraine–Colorado Springs*	2.6
Boulder–Arapahoe Peak at timber line†	3.2
Denver-Corona*	3.6
Boulder–Redrock Lake‡	3.2

* Data from Annual Summary of Colorado Division of the Climatological Service.

† Data from YOUNG, ROBERT T., Forest formations of Boulder County, Colorado. BOT. GAZETTE 46:321–352. 1907.

‡ Data from RAMALEY, FRANCIS, AND ROBBINS, W. W., Studies in lake and streamside vegetation. I. Redrock Lake near Ward, Colorado. Univ. Colo. Studies 6:133–168. 1909.

INVERSION OF TEMPERATURE.[6]—This phenomenon is common in mountainous regions, being particularly noticeable in the spring and autumn. The valleys and canyon bottoms are often cooler than the adjacent hillsides; the plains are cooler and have greater diurnal range of temperature than the overhanging foothills.[7]

A comparative study of temperatures of the University of Colorado campus[8] and the mesas near by, 415 feet higher, showed for May 1908 the mean monthly difference in temperature to be 2°6 higher on the mesas than on the campus. Furthermore, the last frost in the spring was 16 days later on the campus than on the mesa. This inversion is undoubtedly present all along the foothills. Mesas have a milder climate than adjacent plains, and the early spring vegetation is in advance of that on the plains. On account of temperature inversion in canyons and gulches, high altitude forms find their lower limit of distribution in gulches rather than on ridges, and low altitude forms extend farther up the ridges than up the gulches.

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[6] HANN, *l. c.*, p. 252.

[7] In the southern Alleghenies, CHICKERING (J. W., JR., Thermal belts. *Amer. Meteor. Jour.* 1: 213–218. 1884–85), quoting SILAS McDOWELL of Franklin, Macon County, N. C., describes the presence there of a "thermal belt" or "frostless zone" upon the mountain sides, commencing at about 300 feet vertical height above the valley and having a breadth of 400 feet vertical height.

[8] RAMALEY, FRANCIS, Climatology of the mesas near Boulder, Colo., in Studies on mesa and foothill vegetation. Univ. Colo. Studies 6:11–49. 1909.

At certain periods, inversion of temperature of more than local influence occurs along the eastern edge of the foothills, which up to a considerable altitude experience a higher temperature than the plains. LOUD[9] points out that on the eastern slope of the Rocky Mountains in Colorado he has often noticed that elevated stations retain a mild temperature for some time after a cold wave has set in at a lower level.

There is much need of thorough investigation of the amount of temperature inversion for various localities; of determining its limits, time of occurrence, and effect upon the vegetation. There is little doubt that an investigation of such a nature would reveal information of practical importance to horticulturists and throw light on problems of plant distribution.

FROST.—The average date of the last killing frost in spring, of the first killing frost in autumn, and the average length of the growing season (period without frost) are important climatic factors. In Colorado these factors are affected to a considerable degree by temperature inversion, and have a great range on account of altitudinal differences. Grand Junction has the longest growing season of any locality in the state (6 months and 18 days), while on the highest peaks there is no day in the year without frost.

TABLE VI

EFFECT OF ALTITUDE UPON AVERAGE LENGTH OF GROWING SEASON AND AVERAGE DATE OF LAST KILLING FROST

Altitude (feet)	Average date of last killing frost	Average length of growing season (period without frost)
5000 and below	April 28	5 months, 6 days
5000–6000	May 5	4 months, 21 days
6000–7000	May 30	3 months, 21 days
7000–8000	June 6	3 months, 6 days

There are no data for higher altitudes. During the summer of 1908, the length of the growing season at Redrock Lake, altitude 10,100 feet, was about 6 weeks. Table VI shows that the retardation in the development of vegetation is about 13 days for every 1000 feet increase in altitude.

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[9] LOUD, F. H., The Colorado sky 1:1–9. 1908.

HUMIDITY

Unfortunately very little information regarding the relative humidity of different parts of Colorado is to be had. The state as a whole, however, has a low relative humidity. Along the eastern border of the state the mean annual relative humidity is about 60 per cent.; east of the foothills the mean annual amount is 48–50 per cent.; in the extreme western part of the state the annual relative humidity is 46–50 per cent. In the mountains there are rapid variations and great extremes of relative humidity.[10] The following from HANN (*l. c.* 289) gives the seasonal march of relative humidity on Pike's Peak, altitude 14,147 feet: winter, 79 per cent.; spring, 81 per cent.; summer, 75 per cent.; autumn, 77 per cent.; year, 78 per cent. Over the entire state, the relative humidity is greatest in the winter. Because of low relative humidity thin-leaved plants are almost unknown in the state, only a very few being able to maintain themselves in the densest shade of steep-walled canyons.

WIND

On the western slope the average wind velocity is 5–6 miles per hour; on the eastern slope 7–7.5 miles per hour; on the northern and eastern borders 10 miles per hour. In the higher mountains, especially on exposed ridges and peaks, the wind has a great velocity and blows almost steadily the year round. Here the winters are extremely windy. Over the whole state, the prevailing direction of the wind is from the west. Along the eastern base of the mountains there occur, during the winter and early spring, warm west winds, called "chinooks." These cause the sap to flow and the buds to swell, only to be followed by a low temperature which proves destructive to vegetation. Mountain and valley winds, which during the day blow up the valleys and at night toward the plains, bring about diurnal variations of humidity, cloudiness, and precipitation. As a result of the day direction of the winds, the mountains are often visited by afternoon showers.

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[10] I am informed by Professor FRANCIS RAMALEY that records of relative humidity made at Tolland, Colorado, altitude 8889 feet, during the summer of 1909, do not show as great fluctuations as is usually expected in mountain regions.

SUNSHINE AND CLOUDINESS

Colorado is a state of sunshine. On the average, 50 per cent. of the days are clear, 33 per cent. partly cloudy, and 17 per cent. cloudy.

Vegetation

PLAINS[11]

Precipitation: mean annual 10–20 inches; about 75 per cent. during the growing season; small amount of snow. *Temperature:* mean annual 45°–50° and above; mean summer 65°–70° and above; mean annual range 40°–50°; diurnal range great. Average date of the last spring frost varies in different localities from April 28 to May 10; average length of growing season about 5 months, 6 days. *Relative humidity:* annual amount 50–60 per cent.

The plains are generally spoken of as including that portion of the state east of the foothills. The climatic and vegetative conditions vary, however, in different parts. The "high plains"[12] north of the South Platte River, the Arkansas-Platte Divide, and the high lands east of the foothills in the southern part of the state are regions over which foothill forms have extended. It will be observed from *figs. 5* and *6* that these areas have a lower mean annual temperature (45°–50°) and a lower mean summer temperature (65°–70°), with a consequent less evaporation rate than the plains proper.

Over the entire plains area grasses are the dominant forms of vegetation; in some places not more than 25 per cent. of the ground is covered. Some of the common grasses are *Andropogon Hallii* Hack., *Calamovilfa longifolia* (Hook.) Hack., *Bouteloua oligostachya* (Nutt.) Torr., and *Bulbilis dactyloides* (Nutt.) Raf. *Eurotia lanata* (Pursh) Moq., *Sarcobatus vermiculatus* (Hook.) Torr., and *Chrysothamnus graveolens* (Nutt.) Greene are abundant in many localities. On ridges and buttes occur various shrubs, such as *Yucca glauca* Nutt., *Prunus Besseyi* Bailey, and *Ceanothus pubescens* (T. and G.) Rydb., also various mat and rosette-forming herbs. *Populus angustifolia* James, *P. Sargentii* Dode, *P. acuminata* Rydb., *P. Wislizenii* (S.

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[11] The classification of the plant zones into plains, foothill, montane, subalpine, and alpine are as outlined by RAMALEY, FRANCIS, Plant zones in the Rocky Mountains of Colorado. Science N. S. **26**:642, 643. (Nov. 8) 1907.

[12] RAMALEY, FRANCIS, Scientific expedition to northeastern Colorado; 8. Botany. Account of collections made. Univ. Colo. Studies **4**:161–164. 1907. This report gives a list of plants characteristic of the "high plains."

Wats.) Sarg., and *Salix* spp. fringe the streams. East of the continental divide, *P. Wislizenii* occurs only in the southern part of Colorado.[13] *Opuntia arborescens*, the chandelier cactus, extends over large areas in the Arkansas Valley; this plant is also restricted in its distribution on the plains to the southern part of the state.

In their *Phytogeography of Nebraska*, POUND and CLEMENTS have divided that state into four regions, two of which, the sand-hill region and the foothill region, extend into Colorado. The sand-hill region in Colorado includes a narrow strip along the eastern part of the state. Their "foothill region," so called because of the great number of mountain plants which here find their eastward distributional limit, occupies the rest of the plains area. In describing the general appearance of the sand-hill region, they say: "The most noticeable character of the sand-hill vegetation, after one has become accustomed to the great variety of species which the sparse vegetation of each hill affords, is its extreme monotony. This is due to the predominance of bunch grasses, which are the controlling element in the covering of the hills, hillsides, sandy ridges, and sandy tablelands of the water sheds. The principal formation of the sand-hills, then, is the bunch grass formation, a grass formation of exposed hills and ridges of pure sand."

EASTERN LOWER FOOTHILLS AND MESAS[14]

Precipitation: mean annual 15–20 inches; about 75 per cent. during the growing season; in the northern part of the state the early spring is the wettest season, in the southern part July and August are the wettest months; more snow than on the plains. *Temperature:* mean annual 45°–50°; mean summer 65°–70°; mean annual and diurnal ranges less than on the plains. Average date of last spring frost April 27 to June 16. As a result of temperature inversion, the mesas are not subject to as late spring frosts as are the adjacent plains. Average length of growing season (period without frost) about 4 months, 21 days. *Relative humidity:* mean annual 48–50 per cent.

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[13] The writer recently found a few trees of this species at localities in the southern part of Rio Blanco County. This locality is west of the continental divide and far north.

[14] The following botanical papers discuss quite fully the ecology of the eastern lower foothills and mesas of northern Colorado: RAMALEY, FRANCIS, Botany of northeastern Larimer County, Colorado. Univ. Colo. Studies **5**:119–131. 1908. RAMALEY, FRANCIS, AND ROBBINS, W. W., Ecological notes from north-central Colorado. *Ibid.* **5**:111–117. 1908. ROBBINS, W. W., Studies of mesa and foothill vegetation; 4. Deciduous trees and shrubs of the mesas. *Ibid.* **6**:36–49. 1908. ROBBINS, W. W., AND DODDS, G. S., Studies in mesa and foothill vegetation; 3. Distribution of conifers on the mesas. *Ibid.* **6**:31–36. 1908.

The lower foothills and mesas of northeastern Colorado represent the meeting ground of grass and forest formations. The trees here are Rocky Mountain yellow pine and Douglas fir (*Pseudotsuga mucronata* [Raf.] Sudw.), the latter occurring in the moister situations. The Rocky Mountain yellow pine meets the grassland formation on the lower parts of the mesas; this formation consists chiefly of *Bouteloua oligostachya* and *Koeleria cristata* (L.) Pers. *Cercocarpus parvifolius* Nutt., the mountain mahogany, and *Yucca glauca* are common on ridges. Other common shrubs of this region are *Prunus melanocarpa* (A. Nels.) Rydb., *P. pennsylvanica* L.f., *Symphoricarpos occidentalis* Hook., *Rhus trilobata* Nutt., *R. glabra* L., *Ribes longiflorum* Nutt., *R. pumilum* Nutt., *R. vallicola* Greene, *Opulaster* spp., *Ceanothus Fendleri* A. Gray, *C. pubescens* (T. and G.) Rydb., *Crataegus* spp., *Rosa Sayi* Schwein., *Berberis repens* Lindl., and *Edwinia americana* (T. and G.) Heller.

The lower foothills and mesas of southeastern Colorado differ from the corresponding regions in northern Colorado. The mesas are grassland composed chiefly of *Bouteloua oligostachya.* Scrub oak and mountain mahogany form a chaparral between the grassland and Rocky Mountain yellow pine formations of the lower foothills. Pinyon pine (*Pinus edulis* Engelm.), the one-seeded juniper (*Sabina monosperma* [Engelm.] Rydb.), and the Rocky Mountain juniper (*Sabina scopulorum* [Sarg.] Rydb.) are common in the lower portion of the foothills. The Rocky Mountain yellow pine and other foothill forms extend far out on the Arkansas-Platte Divide.[15]

EASTERN UPPER FOOTHILLS

Precipitation: mean annual 15–20 inches; about 75 per cent. during the growing season; the early summer is the season of maximum rainfall. *Temperature:* mean annual 40°–45°; mean summer 60°–65°; mean annual range

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[15] For an extended account of the mesas and foothills of southern Colorado see the following papers: SHANTZ, H. L., A study of the vegetation of the mesa region east of Pike's Peak; the Bouteloua formation. BOT. GAZETTE **42**:16–47, 179–207. 1906. SCHNEIDER, E. C., The distribution of woody plants in the Pike's Peak region. Colorado Coll. Publ. Science Series **12**:137–170. 1909.

30°–40°; diurnal range decreases with an increase of altitude. Average date of last spring frost May 30 to June 31; average length of growing season 3 months, 21 days, to 3 months, 6 days. *Relative humidity:* annual amount greater than on plains and mesas.

This area extends the full length of the state along the eastern slope. It is between the altitudes of 6000 and 8000 feet. It is dominated by a forest of Rocky Mountain yellow pine and Douglas fir. The upper limit of the zone is coextensive with the upper limit of abundant growth of Rocky Mountain yellow pine. South Park, although mostly above 8000 feet, has a foothill vegetation and should be classed as upper foothill country. It is much drier than localities at the same altitudes on the eastern slope. It is an upland country supporting a xerophytic vegetation.[16]

MONTANE ZONE

Precipitation: mean annual 15–20 inches; many localities have greater amounts; July and August are the wettest months; snow abundant. *Temperature:* mean annual 35°–40°; mean summer 55°–60°; mean annual and diurnal ranges of temperature generally small but varying greatly with exposure. No data for average date of last spring frost and average length of growing season. *Relative humidity:* fluctuating between high and low; annual amount increases with increase of altitude.

This zone roughly includes those portions of the state with an altitude between 8000 feet and 10,000 feet. On the western slope and on the minor mountain ranges and plateaus of the western part of the state, the montane zone often extends to higher altitudes, which is due chiefly to the generally drier condition of this slope.

The vegetational composition and appearance of the montane zone varies in different sections of Colorado. In the northeastern part of the state it is dominated by lodgepole pine, being adjoined by the Rocky Mountain yellow pine forests of the foothills and the Engelmann spruce forests of the subalpine regions. Other less abundant conifers of this zone are the bristle cone pine (*Pinus aristata* Engelm.), limber pine (*Pinus flexilis* James), Colorado blue spruce (*Picea Parryana* [Andree] Sarg.), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.). In southern Colorado lodgepole pine does not form so extensive forests as it does in the northern part of the state. East and west of the continental divide the white fir (*Abies concolor* Lindl.) occurs in the montane zone of southern Colorado, but not in the northern part. Aspen (*Populus tremuloides* Michx.) is common throughout the montane zone in all parts of the state, but particularly so on the western slope. There it covers extensive areas and grows to a considerable size. In northwestern Colorado it often dominates extensive areas, or may be mixed with lodgepole pine. Here oak shrubbery is often abundant in the lower parts of the zone. In southwestern Colorado the montane zone extends between the altitudes 9000 feet and 10,500 feet and is chiefly aspen-covered.

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[16] RAMALEY, FRANCIS, Plants of the Florissant region in Colorado. Univ. Colo Studies **3**:178–185. 1906.

SUBALPINE ZONE

Precipitation: mean annual above 20 inches; often 35 or 40 in some localities; maximum amount in the summer; daily afternoon showers common. *Temperature:* mean annual below 35°; mean summer below 55°; mean annual and diurnal ranges low. *Relative humidity:* fluctuating between high and low but generally high.

In all parts of the state, except the extreme southern part, this zone extends from an average altitude of 10,000 feet to timber line; it is the highest timbered zone. The dominant and characteristic tree in all parts of the state is the Englemann spruce. It is nearly always accompanied by limber pine and subalpine fir. Other common trees and shrubs are *Salix chlorophylla* Anders., *S. glaucops* Anders., *S. Bebbiana* Sarg., *S. pseudolapponum* Seem., *Betula glandulosa* Michx., *Ribes parvulum* (A. Gray) Rydb., *R. lentum* (Jones) Coville & Rose, *Sambucus microbotrys* Rydb., and *Lonicera involucrata* Banks. *Vaccinium oreophilum* Rydb. and *V. caespitosum* Michx. are common shrubs growing on the forest floor. Meadows and swampy areas are abundant throughout the zone.

TIMBER LINE.—Timber line is the upper limit of tree growth. In Colorado it usually marks the limit above which trees are climatically excluded. HARVEY[17] has pointed out that timber line on Mt. Ktaadn in Maine is not climatic but physical. COOPER,[18] although recognizing timber line to be a climatic division line, has shown that in the Long's Peak region, Engelmann spruce has not reached the point where tree growth is climatically excluded, and that the present timber line as represented by Engelmann spruce is not the true climatic timber line. In this region, however, limber pine forms a true climatic timber line.

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[17] HARVEY, L. H., A study of the physiographic ecology of Mt. Ktaadn, Maine. Univ. Maine Studies. 1903.

[18] COOPER, W. S., Alpine vegetation in the vicinity of Long's Peak, Colorado. BOT. GAZETTE **45**:319–337. 1908.

The average height of timber line in Colorado is near 11,500 feet. It is higher on the ridges than in the gulches, on south and west exposures than on north and east exposures. Engelmann spruce, subalpine fir, and limber pine are the principal timber line trees.

ALPINE ZONE

Climatic conditions for this zone in Colorado are not well known. The lower limit of the alpine zone is timber line. Although precipitation is ample and the relative humidity frequently high, tree growth is absent partly because of the thin soil, steep slope which cannot retain sufficient moisture, low air and soil temperatures, high winds, snow,[19] rapid transpiration, and liability to frosts. The lower portions of the zone are covered with grasses and low alpine mat forms. The upper parts are usually rock fields supporting little except a lichen vegetation.

Some of the most common alpine plants of Colorado are *Deschampsia caespitosa* (L.) Beauv., *Phleum alpinum* L., *Trisetum subspicatum* (L.) Beauv., *Festuca brachyphylla* Schultes, *Carex atrata* L., *Polygonum viviparum* L., *Silene acaulis* L., *Caltha leptosepala* Hook., *Dryas octopetala* L., *Clementsia rhodantha* (A. Gray) Rose, *Sieversia turbinata* (Rydb.) Greene, *Castilleja occidentalis* Torr., *Campanula petiolata* DC, *Mertensia alpina* (Torr.) Don., *Rydbergia grandiflora* (T. and G.) Greene, *Artemisia scopulorum* A. Gray, *Eritrichium argenteum* Wight, *Trifolium dasyphyllum* Torr., *T. Parryi* A. Gray, and *Tetraneuris lanata* (Nutt.) Greene.[20]

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[19] SHAW, C. H., Causes of timber line on mountains. Plant World **12**:169–181. 1909.

[20] For a list of the alpine plants of Colorado with statistics of their geographical distribution, see article by COCKERELL, T. D. A., Alpine flora of Colorado. Amer. Nat. **40**:861–873. 1906.

SAN LUIS VALLEY

Precipitation: mean annual below 10 inches; about 75 per cent. during growing season; July and August wettest months; small amount of snow. *Temperature:* mean annual 40°–45°; mean summer 60°–65°; mean annual and daily range great. Average date of last spring frost May 24 to June 12; average length of growing season (period without frost) 3 months, 15 days. *Relative humidity:* low.

This dry, level country is covered with *Artemisia tridentata*, which spreads over extensive areas, the plants often reaching a height of 8 feet. *Chrysothamnus* spp., *Sarcobatus vermiculatus*, and *Atriplex* spp. are abundant, alternating in some places with bunch grasses. On the slopes occur pinyon pines, cedars, and Rocky Mountain yellow pines. The higher plant zones are very similar to corresponding zones in other parts of southern Colorado.

The level parts of San Luis Valley have the same altitude as the eastern foothill region (7000–9000 feet). The climatic conditions are practically the same, with the exception of the precipitation and the daily and annual ranges of temperature. In the eastern foothills the precipitation is 15–20 inches; in San Luis Valley below 10 inches. In the eastern foothills the ranges of temperature are considerably less than in San Luis Valley. In comparing the monthly temperatures of Garnett, San Luis, and Saguache, all in San Luis Valley, with Idaho Springs, Georgetown, and Silver Cliff, all within the eastern foothills, it was found that, although the mean summer and mean annual temperatures were about the same, the winters of San Luis Valley are much severer than those of the foothills, the months of December, January, and February being 10°–15° colder. As a result of these differences in range of temperature and rainfall, the foothills support a forest growth, while grass and sage predominate in San Luis Valley.

MIDDLE PARK

Climatological data for this region are not sufficient to be of much use. It is very probable, however, that the lower and flatter portions of the park have nearly 10 inches of rainfall. There are great extremes of temperature. *Artemisia tridentata* produces the principal formation on the dry, level stretches. It is associated with *Chrysothamnus* spp. and *Symphoricarpos oreophilus* A. Gray. Other common shrubs growing on dry hillsides are *Kunzia tridentata* (Pursh) Spreng., *Amelanchier elliptica* A. Nels., and *Holodiscus dumosus* (Nutt.) Heller. Grassland alternates with the sage in mesophytic level places. The hills, except south exposures, are covered with lodgepole pine. Engelmann spruce occurs in the deep and narrow canyons, even in the lower parts of the park, but it is not abundant below 9000 feet. Rocky Mountain yellow pine is very uncommon in Middle Park.[21]

WESTERN SAGE PLAINS AND LOWER FOOTHILLS

Under this head will be discussed that portion of the state west of the continental divide, which extends up to the montane zone, with the exception of Middle Park.

Precipitation: below 10 inches in the western part and 10–15 inches in the eastern part; about 50 per cent. during the growing season. *Temperature:* mean annual 40°–50° and above; mean summer 60°–70° and above; mean annual range above 45; diurnal range great. *Relative humidity*: generally low.

The dominant forms of vegetation of this area are sage brush, pinyon pine, scrub oak, and Rocky Mountain yellow pine. The northwestern part of the state, however, has climatic conditions which are appreciably different from those of the middle and southwestern part (see *figs. 5* and *6*). In the former area the mean annual and mean summer temperatures are about 5° cooler than in the southwestern area, and although the precipitation is about the same in amount and distribution, the effect of the lower temperature is indicated by the lower altitudinal distribution of typical arborescent forms. In northwestern Colorado, Rocky Mountain yellow pine grows to some extent on slopes between 6000 feet and 8000 feet; scrub oak occurs between the same altitudes; aspen comes in abundantly at 7500 feet, and scattered groves are found at lower elevations. In southwestern Colorado, Rocky Mountain yellow pine is not abundant below 8000 feet; scrub oak is seldom abundant below 8000 feet, and aspens do not occur commonly below 9000 feet.

In southwestern Colorado along streams, *Populus angustifolia, Lonicera involucrata,* and *Lepargyraea argentea* (Nutt.) Greene are common. Sage plains stretch from the streams to the foothills; associated with the sage is *Sarcobatus vermiculatus*. Other characteristic shrubs are *Fendlera rupicola* Engelm. & Gray, *Peraphyllum ramosissimum* Nutt., *Kunzia tridentata*, *Cercocarpus parvifolius*, *Amelanchier alnifolia* Nutt., and *Yucca baccata* Torr. The alkaline flats are covered with chenopodiaceous plants.[22] The foothills up to 7500 feet are covered with pinyon pines and cedars. Above these come Rocky Mountain yellow pine, forming a distinct zone up to 9000 feet.

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[21] The writer is not sufficiently familiar with conditions in North Park to discuss them.

As in southwestern Colorado, the greater portion of middle and northwestern Colorado, up to an altitude of 7500 feet, is covered with sage brush, *Chrysothamnus* spp., and *Sarcobatus vermiculatus*. There is very little grassland country until an altitude of 7000 feet is reached. Oak chaparral grows to some extent below 7500 feet, but in many localities forms a distinct zone between the pinyon-cedar and montane zones. Pinyon pine and cedars are common associates here as in other parts of Colorado. On the lower slopes cedar is predominant, forming nearly 90 per cent. of the tree growth; at higher altitudes pinyon becomes relatively more abundant. Sage brush reaches the height of its development, both in size and numbers, on level expanses below 7500 feet; it extends up to 10,000 feet, however, being confined to dry ridges. *Populus angustifolia*, *Alnus tenuifolia* Nutt., *Lepargyraea argentea*, and *Crataegus* spp. are common streamside plants up to an altitude of 7000 feet. *Cercocarpus parvifolius*, *Amelanchier oreophila* A. Nels., *Symphoricarpos* spp., and *Kunzia tridentata* occur on dry and stony hillsides.

It is generally held that the vegetation and flora of the eastern slope is very different from that of the western slope. This is especially true for altitudes below 8000 feet. The vegetation of the alpine, subalpine, and to a less extent of the montane zones, however, is very similar on both slopes. Below 8000 feet the climatic and zonal relations are quite different on the two slopes. On the eastern slope the foothill zone extends from an altitude of 8000 feet down to 6000 feet, and is an area timbered with Rocky Mountain yellow pine. On the western slope, localities between 6000 feet and 7500 feet are dry, having a precipitation 5 to 10 inches less than similar altitudes of the eastern slope; the vegetation is chiefly sage brush, associated with *Sarcobatus vermiculatus* and *Chrysothamnus* spp. Pinyon pine and cedars occur on the ridges. Rocky Mountain yellow pine is scattered in northwestern Colorado; it extends up to 8000 feet, but forms no distinct zone. Below 6000 feet east of the continental divide are grass-covered plains with a precipitation of 10–20 inches. At the same altitudes on the western slope one meets with semi-desert conditions. The annual precipitation is below 10 inches and the vegetation is predominantly sage brush.

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[22] For excellent discussions of the flora and vegetation of the southwestern part of Colorado see the following articles: BRANDEGEE, T. S., The flora of southwestern Colorado. Bull. U. S. Geol. and Geog. Surv. of the Territories (Hayden Survey) **11**: 227–248. EASTWOOD, ALICE, Report on a collection of plants from San Juan County in southeastern Utah. Proc. Cal. Acad. Sci. 6:270–329. 1896. BAKER, CARL F., AND EARLE, F. S., Narrative accounts of collecting trips in southern and western Colorado in *Plantae Bakerianae*.

In general it may be said that the state west of the continental divide is drier from the vegetation standpoint than the eastern slope. Only about 50 per cent. of the rainfall on the western slope occurs during the growing season, in contrast with the occurrence on the eastern slope of about 75 per cent. during the same period. Hence for any two localities east and west of the continental divide with equal annual precipitation amounts, the locality west will have the more xerophytic vegetation.

In connection with the preparation of this paper, the writer wishes to express his deep appreciation of helpful suggestions and criticisms given by Professor FRANCIS RAMALEY.

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